Upstream Fish Passage at a Resistance Board Weir Using Infrared and Digital Technology in the Lower Stanislaus River, California

2006−2007 Annual Data Report

Prepared by:

Jesse T. Anderson, Clark B. Watry and Ayesha Gray

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Summary

We used a resistance board weir equipped with an infrared scanner and digital camera (Vaki RiverWatcher) to collect abundance, run timing, and biological data from salmonids and other incidental species in the Stanislaus River, a tributary to the San Joaquin River, California. The weir was installed and began monitoring on September 8, 2006 and operation ceased on June 25, 2007. During this period, we counted 3,078 Chinook salmon (*Oncorhynchus tshawytscha*). Peak passage (27% of entire run) occurred on November 13 and 14. Biological data, including species, sex, presence of an adipose fin, length, and scale samples were collected from 64 Chinook salmon captured in the weir's live trap. Using the RiverWatcher, we determined sex ratio and adipose fin presence for all Chinook salmon. Females comprised 52% of the escapement population while 2% of the population had adipose fin clips, indicating hatchery origin. The average total length of male and female Chinook salmon with adipose fins was 821 mm and 745 mm, respectively. In all, 12 *O. mykiss* were also counted during the sampling period; average total length was 455 mm for these fish. Other fish species counted at the weir included 3,388 Sacramento sucker (*Catostomus occidentalis*), 451 Sacramento pikeminnow (*Ptychocheilus grandis*), 390 hardhead (*Mylopharodon conocephalus*), 240 striped bass (*Morone saxatilis*), 171 common carp (*Cyprinus carpio*), 81 unknown *Ictalurus* spp. and/or *Ameiurus* spp., 73 Sacramento blackfish (*Orthodon microlepidotus*), 53 American shad (*Alosa sapidissima*), 36 black bass (*Micropterus* spp.), 5 goldfish (*Carassius auratus*), and 2 chum salmon (*Oncorhynchus keta*). Daily average flow recorded at Ripon, CA (CDEC – http://cdec.water.ca.gov) ranged between 462 and 1,790 ft^3/s. Water temperature recorded at Ripon during the monitoring period ranged from 7.8°C to 23.4°C, instantaneous turbidity at the weir site ranged from 0.2 to 7.1 NTU, and dissolved oxygen at Ripon ranged from 7.6 – 11.7 mg/L. Environmental parameters were graphed with passage numbers to display trends.

Introduction

The Stanislaus River, a major tributary to the San Joaquin River in California's Central Valley, provides important spawning and rearing for Chinook salmon (*Oncorhynchus tshawytscha*) considered a species of special concern, and steelhead trout (*O. mykiss*), which are listed as threatened under the federal Endangered Species Act (ESA) (NOAA 2005). Historically, various life history types of Chinook salmon inhabited the Stanislaus River, including fall-, late fall-, and spring-runs (Reynolds et al. 1993). Spring-run Chinook salmon have had critically low returns in past decades, and continuing declines of other life history types have raised concerns with state and federal resource agencies.

Like all San Joaquin River tributaries, multiple dams are located on the upper Stanislaus River. Currently, upstream migration for anadromous fishes ends at Goodwin Dam, river kilometer (rkm) 94. Historically, upstream migration and spawning occurred well into the Stanislaus River's three forks, but miles of spawning and rearing habitat were lost due to dam construction (Fry 1961). Additionally, in-channel mining has limited the availability of both spawning and rearing habitat, and water diversion pumps, found throughout the lower section of the Stanislaus and San Joaquin Rivers, divert water for agricultural uses throughout the Central Valley and are known to entrain juvenile salmonids (Foss 2005). Many of these diversions are operated as part of the Central Valley Project (CVP), a collective water delivery effort that began in 1930 to provide irrigation water to valley farmers. Central Valley Project water is conveyed down the Sacramento and San Joaquin river systems until it enters the Sacramento/San Joaquin Delta (Delta) where CVP water mixes with other supplies, such as those of the State Water Project (SWP). Approximately half of the water entering the Delta is pumped south to provide agricultural and municipal water to the lower half of the Central Valley; the remainder discharges into San Francisco Bay and on into the Pacific Ocean (USDOI 2005).

The Central Valley Project Improvement Act (CVPIA) was passed in 1992 to include the protection, restoration, and enhancement of fish and wildlife and their associated habitats. The U.S. Bureau of Reclamation (BOR) and the U.S. Fish and Wildlife Service (USFWS) are responsible for implementing provisions outlined in the CVPIA (USDOI 2005). As a result, the CVPIA granted USFWS authority to establish the Anadromous Fish Restoration Program (AFRP) which has specific objectives to collect data regarding fish population dynamics, health, and habitat conditions to facilitate the evaluation of restoration activities for anadromous fish including American shad, green sturgeon, striped bass, Chinook salmon, and steelhead (USFWS 2001). A major goal of restoration activities is to increase at-risk salmonid populations. Population monitoring is a necessary component to assist AFRP in evaluating the effectiveness of existing and future restoration efforts.

Adult spawner escapement estimates can provide reliable annual abundance estimates, but are also prone to bias if the rigid assumptions of the methodology are violated. The California Department of Fish and Game (CDFG) has conducted annual spawning escapement carcass surveys for fall-run Chinook salmon throughout the Central Valley, including the Stanislaus River, since the late 1940s (Fry 1961). Carcass surveys use post-spawning carcass counts and statistical modeling (Schaefer 1951; Seber 1973; Law 1994) to calculate total escapement for each river reach sampled.

Our method is comparatively new, and provides a more direct assessment of the salmon spawning migration (or escapement). We used a resistance board weir (Tobin 1994), located downstream of known spawning areas, to determine abundance and timing of spawning adult Chinook salmon. Resistance board weirs have been widely used in Alaska to generate salmonid escapement estimates since the early 1990s (Tobin 1994). In the winter of 2002, Cramer Fish Sciences (CFS) installed a resistance board weir in the lower Stanislaus River, located at rkm 50.6, to test the use of Alaskan weir technology for monitoring salmonid populations in the Central Valley. We originally constructed the weir using a combination of resistance board panels (Tobin 1994; Stewart 2002, 2003) and rigid weir panels. A series of panel and component modifications (compared to Tobin 1994 and Stewart 2002, 2003) tailored the resistance board

weir to its current site. We demonstrated the utility of resistance board weir technology in the Stanislaus River in the 2002 season, and in 2003, improved the system with the addition of a passive infrared RiverWatcher Fish Counter (RiverWatcher), manufactured by Vaki Aquaculture Systems Ltd. (Kopavogur, Iceland), which enumerated adult salmon passing the weir using infrared and digital technology. Shardlow and Hyatt (2004) demonstrated the RiverWatcher system to be >95% accurate for Pacific salmon with migration rates of less than 500 fish/h (a high rate of passage). Other studies found RiverWatcher accuracy to be even higher (nearing 100%) (Fewings 1994; Eatherley et al. 2005). Data collected in subsequent seasons on the Stanislaus River proved highly effective for enumerating run size and timing of Chinook salmon and steelhead that cannot be ascertained through traditional carcass surveys, as well as enumerating other fish species. We made incremental improvements in weir operations and RiverWatcher data collections with each passing season. These improvements included a color digital camera in place of a black and white camera, an upgraded lighting system to capture clear night time passage photos, and creation of a "viewing lane" for the fish to pass through and allow the camera to capture high-quality photographs.

The three main objectives of the Stanislaus River weir project were to:

1. Determine total Chinook salmon and steelhead escapement in the Stanislaus River through direct counts;

2. Evaluate the effects of environmental factors on the migration timing of fall-run Chinook salmon; and,

3. Validate traditional carcass survey estimates by comparing weir and CDFG estimates of population size, run timing, and life history composition.

The following annual data report includes detailed information regarding the 2006–2007 weir monitoring season. Additional information and analysis of weir data from 2002–2007 is forthcoming in a comprehensive project report.

Study Area

The snow-fed Stanislaus River is one of three major tributaries to the lower San Joaquin River system (Figure 1). Its headwaters begin at an elevation of approximately 3,675 m and drain approximately 240,000 ha of the Central Sierra Nevada (Kondolf et al. 2001). The river flows in a general westerly direction to its confluence with the San Joaquin River (elevation 30.5 m) approximately 14.5 km west of the town of Ripon, California. From the Stanislaus River confluence, the San Joaquin River flows northward into the Delta. Agriculture and urban development are the most common land uses adjacent to the Stanislaus River. River flow is regulated by multiple dams including New Melones, Tulloch, and Goodwin used for municipal, agricultural irrigation, power generation, recreation, and flood control (Appendix 1). Typical of regulated rivers in the Central Valley, the river channel is deeply incised and flood control dikes (12,500 ft^3/s maximum capacity) line the majority of the lower river to protect urban and agricultural lands. California Data Exchange Center (CDEC) provides flow information which varies substantially between years at the weir site (Figure 2).
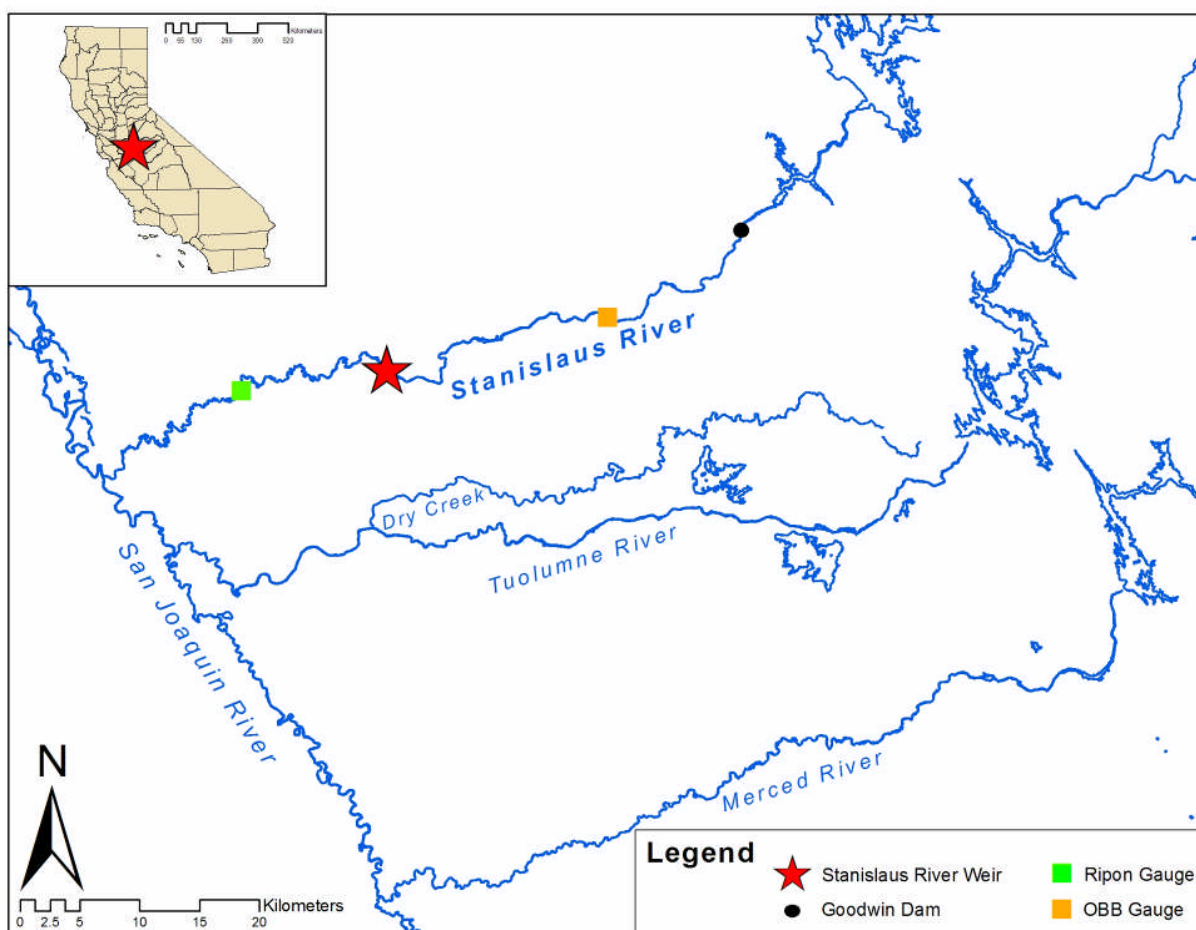
Figure 1. The lower Stanislaus River in relationship to the San Joaquin River and its main tributaries in the Central Valley, California.
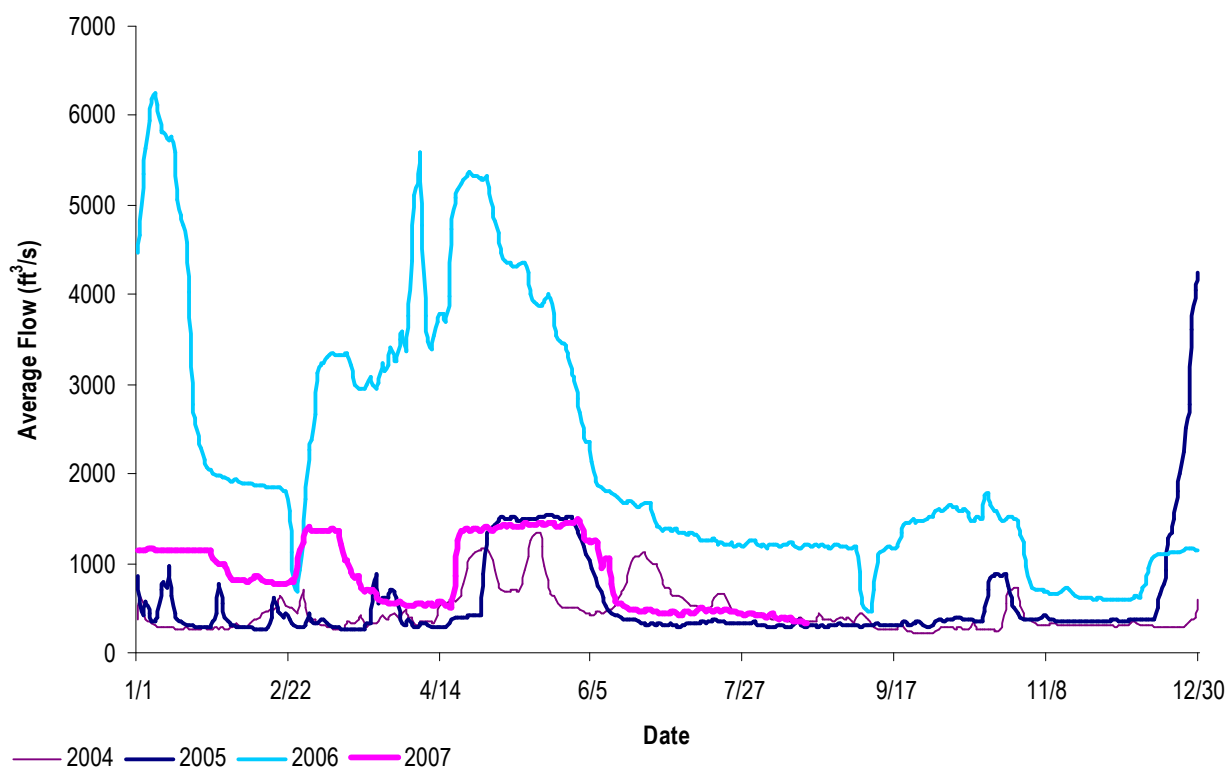
Figure 2. Average daily flow for January 2004 – October 2007 on the Stanislaus River at Ripon (RIP) (Data source: CDEC – http://cdec.water.ca.gov).

The U.S. Geological Survey places the Central Valley in the Pacific Border Province – California Trough physiographic region. The U.S. Forestry Service places the location's ecoregion as the California Dry Steppe Province. Annual air temperatures can range from below freezing in the winter to well above 38ºC during midsummer. The Stanislaus River riparian corridor is home to a wide variety of flora and fauna including a variety of fishes. In addition to Chinook salmon and steelhead, many other fishes may be found in the Stanislaus River (Appendix 2). River channel substrate at the weir site is composed of small- to medium-sized gravel, sand, and fines, with a rather uniform channel cross-section (approximately 30 m wide at 500 ft^3/s). The riparian corridor is characterized by Freemont cottonwood (*Populus fremontii*), white alder (*Alnus rhombifolia*), box elder (*Acer negundo*), valley oak (*Quercus lobata*), western sycamore (*Platanus racemosa*), sandbar willows (*Salix exigua*), wild rose (*Rosa californica*), California blackberry (*Rubus ursinus*), coyote bush (*Baccharis pillularis*), and many native and non-native grass species (Sacramento River Partners 2001). Non-native vegetation includes Himalaya blackberry (*Rubus discolor*), tree of heaven (*Ailanthus altissima*), black locust (*Robinia pseudoacacia*), and many others.

Methods

We installed a 30 m wide resistance board weir (Tobin 1994; Stewart 2002, 2003) at rkm 50.6 on the Stanislaus River and conducted operations from September 8, 2006 – June 25, 2007. This site is the same location used since 2002 and is below the lowest spawning extent in the river, approximately 13.8 rkm downstream from the city of Oakdale, California. Desirable substrate, bank characteristics, and a relatively uniform channel cross-section made this a suitable site for resistance board weir operations (Figure 3). Additionally, relatively shallow water depth (e.g. 0.5 – 2.0 m) is optimum for the operation and maintenance of the RiverWatcher, and is conducive to trapping a sub-sample of fish for biological data collection. Data was also collected from post spawn Chinook salmon and *O. mykiss* that washed up on the weir.

Steelhead and rainbow trout are the same species (*O. mykiss*) with differing life history types (e.g., ocean, estuarine, and river). California Department of Fish and Game considers any *O. mykiss* in excess of 16 inches in total length to be a potential steelhead. Due to the limited number of fish passages recorded at the weir and the overlap in size range of the fish recorded we will consider all fish to be simply "*O. mykiss*" for this report. The majority of the Chinook salmon recorded at the weir are considered to be simply Chinook salmon; however, due to a clear break in passage during March through May along with definitions found in the literature we consider any fish to pass during the months of May and June to be spring-run Chinook salmon (Yoshiyama et al. 1998, Moyle 2002).

Figure 3. The Stanislaus River weir site after equipment removal, June 2007.

Trap Design

We designed the aluminum live trap (1.5 m wide x 4.8 m long) to passively monitor fish or actively trap fish for biological sampling. The 'passing lane' (30.5 cm x 60 cm) was constructed within the live trap, at the downstream entrance, to create a chute to house the set of RiverWatcher scanners (Figure 4 and Figure 5). Once through the passing lane, fish traveled through the 'viewing lane' (30.5 cm x 100 cm) while the digital camera captured still images. The viewing lane frame was constructed of square aluminum tubing (2.54 cm^2). We attached a white acrylic sheet (30.5 cm x 100 cm) on the side opposite the camera to provide a light background and help reflect light to improve overall image quality. Black lines spaced at 10 cm increments (on center) on the white acrylic background aided in length determination. We also installed a clear acrylic window (30.5 cm x 100 cm) on the camera side of the viewing lane. Four white LED 'light tubes' mounted vertically inside the live trap (two on either side of the camera) illuminated the viewing lane at night. Viewing lane design caused migrants to pass in a centered and perpendicular

direction to the camera, so consistent image data could be collected. The live trap was outfitted with five removable lids which could be locked to deter human access into the live trap.
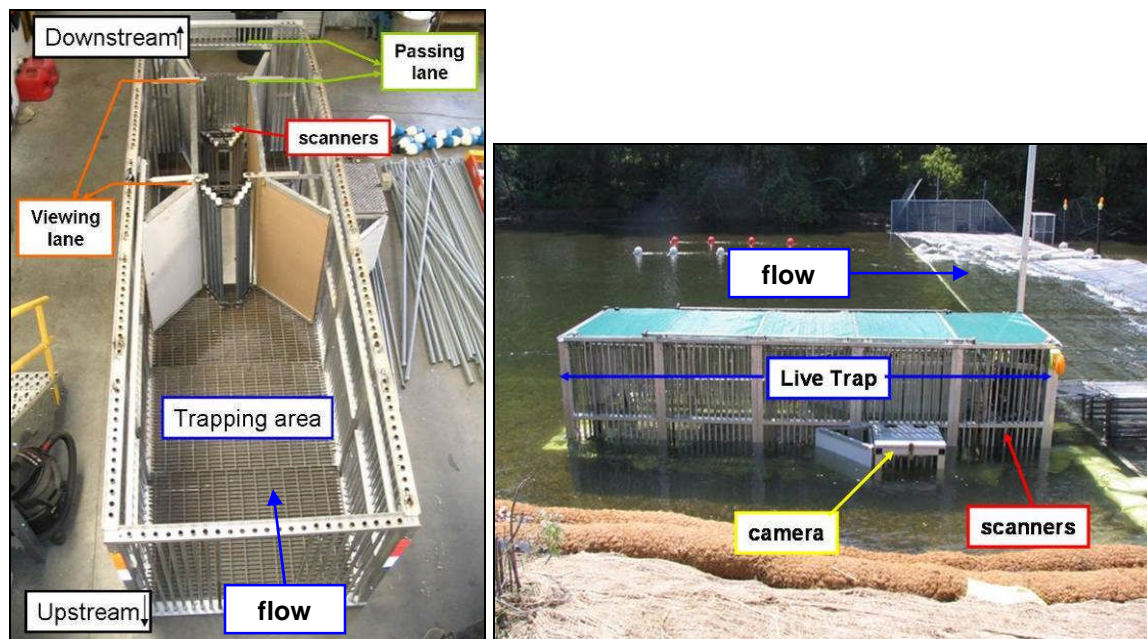
Figure 4. Left: Looking down on the live trap during construction [cover not installed]; acrylic panels leading away from the viewing lane are visible. The large open area at the upstream portion of the live trap is the holding area for captured fish during trapping periods. Right: Upstream live trap with the RiverWatcher camera and scanner system located at the downstream end.
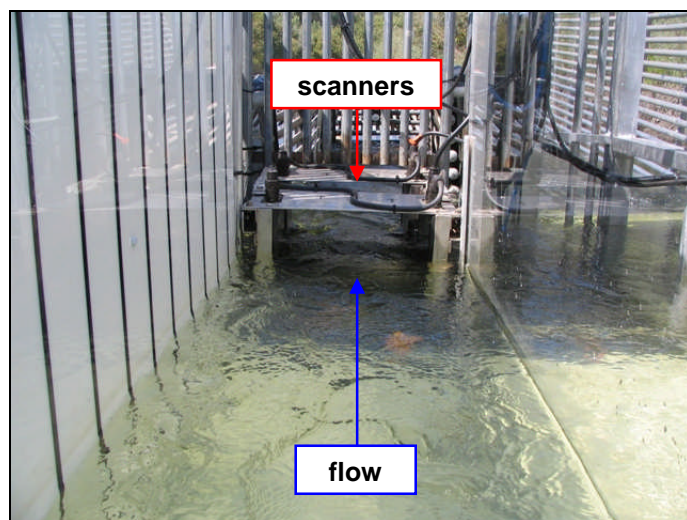
Figure 5. Looking downstream through the viewing lane and the set of scanners (passing lane) during low flow (approximately 350 ft³/s).

RiverWatcher Setup

We installed two tandem RiverWatcher systems within the modified passing lane; the downstream unit (RiverWatcher 1) was a backup to the upstream system (RiverWatcher 2) (Figure 6). RiverWatcher 1 and 2 shared a common power supply; however, RiverWatcher 1 was simply composed of an infrared scanner (scanner) and control unit. In contrast, RiverWatcher 2 was outfitted with a three-part system, including a scanner, digital camera (camera), and a computer. Aside from digital photo imagery, all other data collected by RiverWatcher 1 and 2 were the same.

Figure 6. Top view of the paired RiverWatcher scanners in the passing lane. The arrows on top of each scanner depict the direction of water flow.

Power Source

The facility was powered by eight 6V deep cycle batteries, wired in series to create a 12V DC system. We used two solar panels (0.61 m x 0.91 m) , mounted to a 6.1 m stainless steel pole and platform (Figure 7) to charge the batteries.

Figure 7. Solar panels mounted on a 6.1 m stainless steel pole and protective platform.

Scanner and Camera

Each scanner had two black plastic plates (20 cm x 60 cm; 30 cm apart) mounted inside a stainless steel frame to house and protect the scanner plates. Inside each plate are two columns of infrared light diodes (96 diodes per column) (Figure 8). When an object breaks the plane of light, the scanner creates an outline (silhouette) of the object as it passes through. *Winari*, a software application bundled with the RiverWatcher, was used to record object depth (mm) which we then use to calculate total length using a length-to-depth ratio (e.g. 4.2:1 for Chinook salmon). The program stored a record whenever the maximum depth of the object exceeded 40 mm, which reduced records of debris such as leaves and air bubbles in the water column. We connected a digital camera to RiverWatcher 2 and a switch in RiverWatcher 2 triggered the camera to capture still images of the viewing lane when fish pass upstream (Figure 9). We set the camera to capture four photos each time it was triggered.
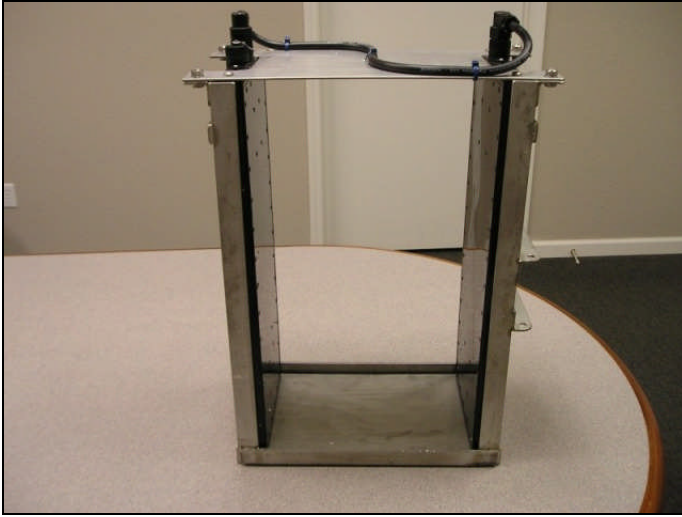
Figure 8. The RiverWatcher scanner unit encased in a protective stainless steel frame.

Figure 9. The RiverWatcher digital camera housed inside a protective aluminum camera box. Note: threaded rods allow for vertical and horizontal adjustment of the camera.

Computer System

We used an independent 'control unit' to store data collected by RiverWatcher 1. We stored all data collected by RiverWatcher 2 to an on-site computer (Figure 10). We downloaded these data daily from the field and imported it into the *Winari* database where silhouettes and digital images were stored and displayed. Separate RiverWatcher 1 and 2 databases aided in final species identification by providing two sets of passage data. Digital images and silhouettes from RiverWatcher 2 were compared to silhouettes from RiverWatcher 1 for all data collected between September 2006 and January 2007; and thereafter, in instances of vandalism, equipment failure, or fish identification questions.

Figure 10. RiverWatcher 2 computer powered by a series of eight 6V deep cycle batteries below.

Image Data Review

Image data (silhouettes and digital photographs) were reviewed daily throughout the season; each passage record contained two silhouettes (Figure 11 and Figure 12), one from each column of diodes. If the passage is an 'up' passage, corresponding photograph data was also reviewed. We chose to use four photographs per passage because the fish is generally well out of the viewing lane by the fifth frame. Morphometric characteristics were used to aid in fish identification when viewing the silhouettes; however, the best data are provided by a clear set of photographs. Photographic data improved the identification process by distinguishing sex, presence of an adipose fin, and determining total length of each fish (Figure 13). We used a key for entering record data (see Table 1).
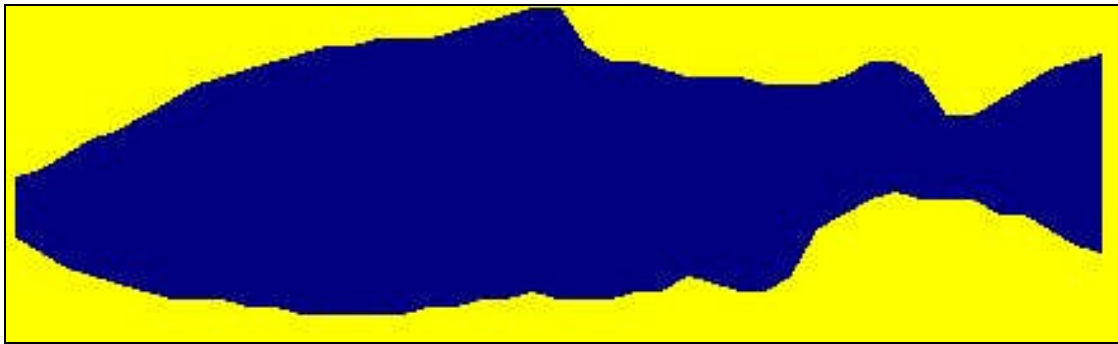
Figure 11. Example of a wild, non-adipose fin clipped male Chinook salmon silhouette.
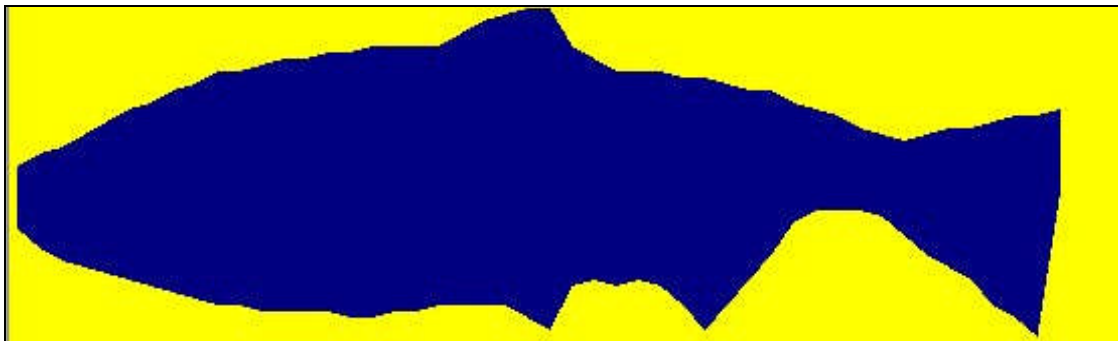
Figure 12. Example of a hatchery, adipose fin clipped male Chinook salmon silhouette.

Figure 13. Left: Example RiverWatcher digital photograph of an adult male Chinook salmon passing through the viewing lane of the upstream live trap at the Stanislaus River weir during the day (left) and at night (right).

Table 1. Key to RiverWatcher acronyms used in the Stanislaus River weir database.

Adipose Fin Clip	ID Certainty	Silhouette Quality	Photo Quality
NA – not applicable	P – positive	None	None
Y – yes	VL – very likely	Poor	Poor
N – no	L – likely	Good	Fair
			Good

Sex	Life Stage	Fish Condition	Photo Problems
NA – not applicable	NA – not applicable	NA – not applicable	NA – not applicable
U – unknown	U – unknown	AB – abrasion	DB – debris
M – male	A – adult	L – laceration	IF – interference
F – female	G – grilse	FI – fungal infection	BO – back out of water
		HS – hook scar	OR – fish orientation
			TB – turbidity
			MP – multiple passage
			EM – equipment malfunction

Biological Sampling

We trapped Chinook salmon and *O. mykiss* for the collection of biological data from November to early December 2006 during low flows (approximately 600 ft^3/s) to safely capture and process fish in the live trap. Our trapping protocols were developed in collaboration with CDFG and determined that a '2-d on, 2-d off' pattern, except during periods of high turbidity (>3 NTU), would be preferable. We considered the live trap closed when the main gate at the upstream end was lifted and locked into place. We installed modified polyvinyl chloride (PVC) 'fykes' in front of both the passing and viewing lanes to discourage trapped fish from exiting the live trap. We continued RiverWatcher operation during trapping events to evaluate our trapping efficiency. When closed, we checked and processed the trap at least twice per day to reduce trapping stress. We took fork length (mm; FL), total length (mm; TL), and depth (mm; maximum girth measured immediately anterior to the dorsal fin insertion point) measurements, photographs, and scale samples (10 scales per fish collected from the 'scale pocket') from each Chinook salmon or *O. mykiss* sampled (Figure 14). In the laboratory, we cleaned and mounted all scale samples. We used CDFG's protocol for cleaning and mounting the scale samples and once mounted the samples were sent to Jason Guignard of CDFG for future age determination and analysis. We also noted species, sex, presence of an adipose fin, and general condition (see Table 1) for each fish handled. Processing generally required 1 to 3 minutes per fish, and once processed were released into a recovery area adjacent to the live trap where they were allowed to rest and continue upstream once ready.
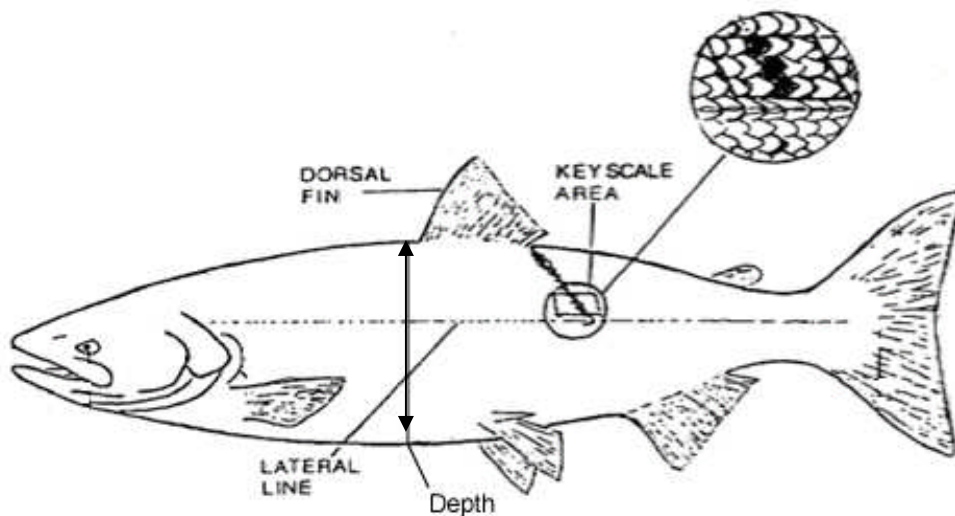
Figure 14. Example of location of the 'key scale area' or 'scale pocket' (PSMFC 2005).

Inspections and Maintenance

We conducted daily weir cleanings and visual inspections for breaches when flows were above 500 ft^3/s and every other day when flows were below 500 ft^3/s. Maintenance procedures generally followed information found in Tobin (1994) and Stewart (2002, 2003) with some site specific modifications. For example, additional floatation during extended periods of high flow was achieved by strapping large, sealed plastic barrels to the downstream side of the resistance board panels (Figure 15).

Figure 15. Added floatation (sealed plastic barrels) enabled the weir to function at sustained high flows; note, modified boat passage panel in foreground.

Environmental Data

We collected environmental data during each inspection including instantaneous water temperature (°C), dissolved oxygen (mg/L), turbidity (NTU), weather conditions (RAN=rain, CLD=cloudy, CLR=clear, FOG=fog), and water velocity (m/s) inside the live trap. Instantaneous water temperature and dissolved oxygen were recorded using a 550A Dissolved Oxygen Instrument (YSI, Inc.), turbidity was measured using a 2020 Turbidimeter (LaMotte Co.), and water velocity was measured using a digital Flow Probe FP-101 (Global Water Instrumentation, Inc.). Other environmental data utilized was downloaded from CDEC and included water flow, temperature, and dissolved oxygen.

Stacking Assessment Surveys

To assess potential Chinook salmon migration delays (stacking), we conducted visual boat surveys 800 m above and below the weir. Two fishery technicians floated each section with one driving the boat and the other standing on the bow with polarized sun glasses. The bow observer counted the number and species of each fish observed. The boat driver recorded the data for each section. We conducted surveys every Monday, Wednesday, and Friday from September 1 – 30, and December 15 – 31. Daily surveys were conducted from October 1 – December 15, and once weekly after December 31. We entered data into the weir database, and calculated the ratio of Chinook salmon observed downstream of the weir and the number recorded by the RiverWatcher passing the weir (stacking ratio). If this ratio was above 15% (D. Marston, CDFG, personal communication), then CFS worked with CDFG to determine if any protocol changes were needed.

Results

Flow from Goodwin Dam (1,200 ft^3/s) was lowered to 400 ft^3/s for a three-day period to allow for weir installation. Upon completion, flow was returned to 1,200 ft^3/s (Figure 16). We began operation of the Stanislaus River Weir on September 8, 2006 and operated continuously through June 25, 2007 (291 consecutive days). The RiverWatcher began running at 1230 hours on September 8, 2006, and ran continuously through 0900 hours on June 25, 2007.
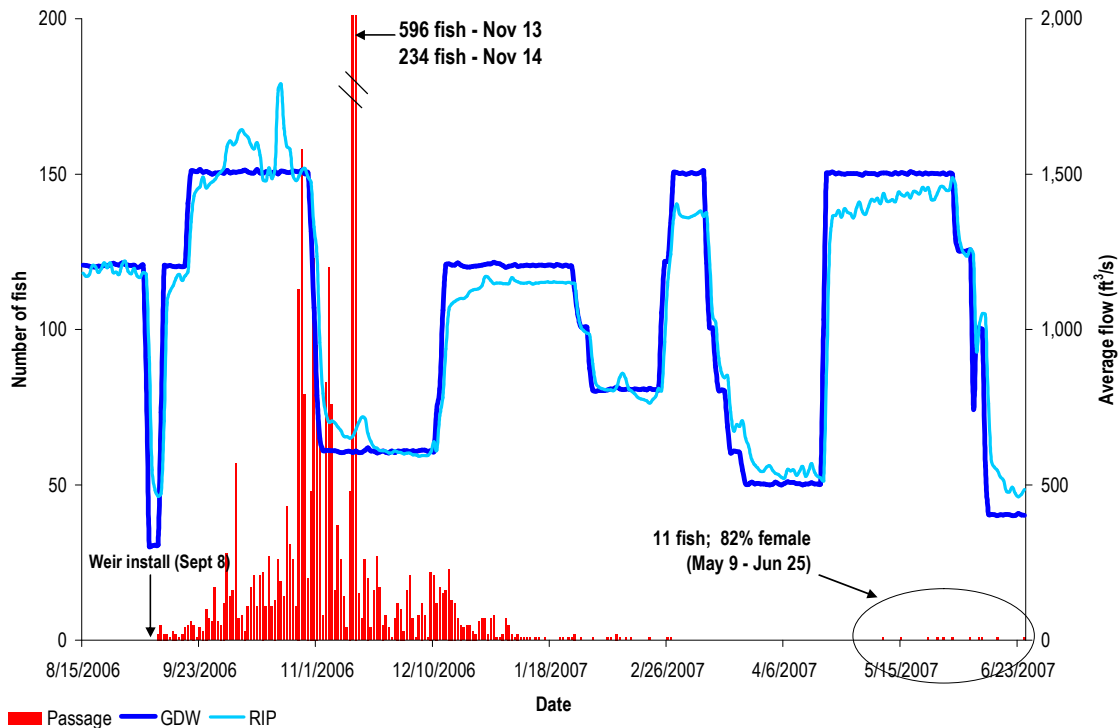
Figure 16. Daily upstream passage of adult Chinook salmon at the Stanislaus River weir and average daily flow at Goodwin Dam (GDW) and Ripon (RIP) between August 15, 2006 − June 25, 2007 [Data source: CDEC – http://cdec.water.ca.gov].

We recorded 3,078 adult Chinook salmon passing the weir. Peak weekly passage (n = 946; 31% of total escapement) occurred between November 12 and November 18 while median cumulative passage occurred on November 6. Highest daily passage (n = 596) occurred on November 13. Only 19% of the cumulative total passage occurred by October 25; however, by November 15, twenty-two days later, 83% of the cumulative total had passed the weir (Figure 17). In all, 98.2% of Chinook salmon passage occurred between September 8 and December 31, 2006 (Figure 18). Approximately 1.4% of total escapement (n = 45) passed between January 1 and February 27, 2007. An additional 11 (0.4%) Chinook salmon were counted between May 9 and June 25, 2007 (Table 2). Diel Chinook salmon passage varied slightly, but was not significant (ANOVA: $F = 0.66$, $P = 0.66$), whereby an apparent decrease generally occurred between 0800 hours − 1159 hours (Figure 19).

Table 2. Chinook salmon RiverWatcher data collected from May 9 − June 25, 2007 (data does not reflect the one 'Up/Down' passage record during this date range).

Sex	Adipose Fin Clip	Range TL (mm)	Mean TL (mm)	95% CI	n
Male	No	958	—	—	1
Male	Yes	743	—	—	1
Female	No	697 - 995	786	786 ± 89	6
Female	Yes	756 - 928	855	855 ± 102	3
Combined		697 - 995	817	817 ± 63	11
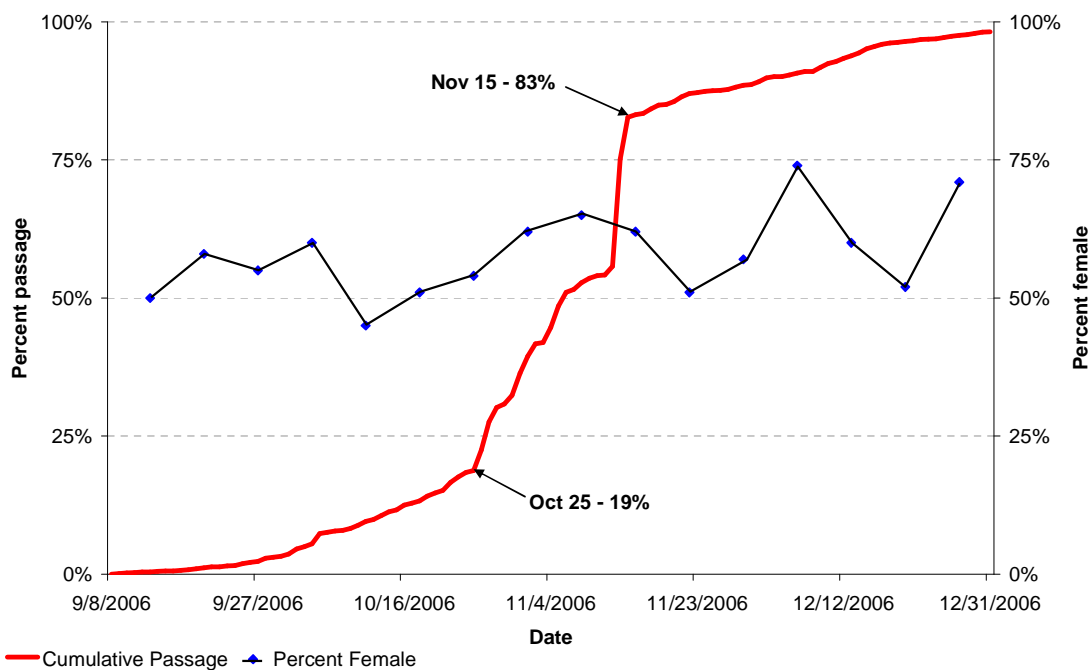
Figure 17. Cumulative adult Chinook salmon passage and the percentage of females from September 8 − December 31, 2006.

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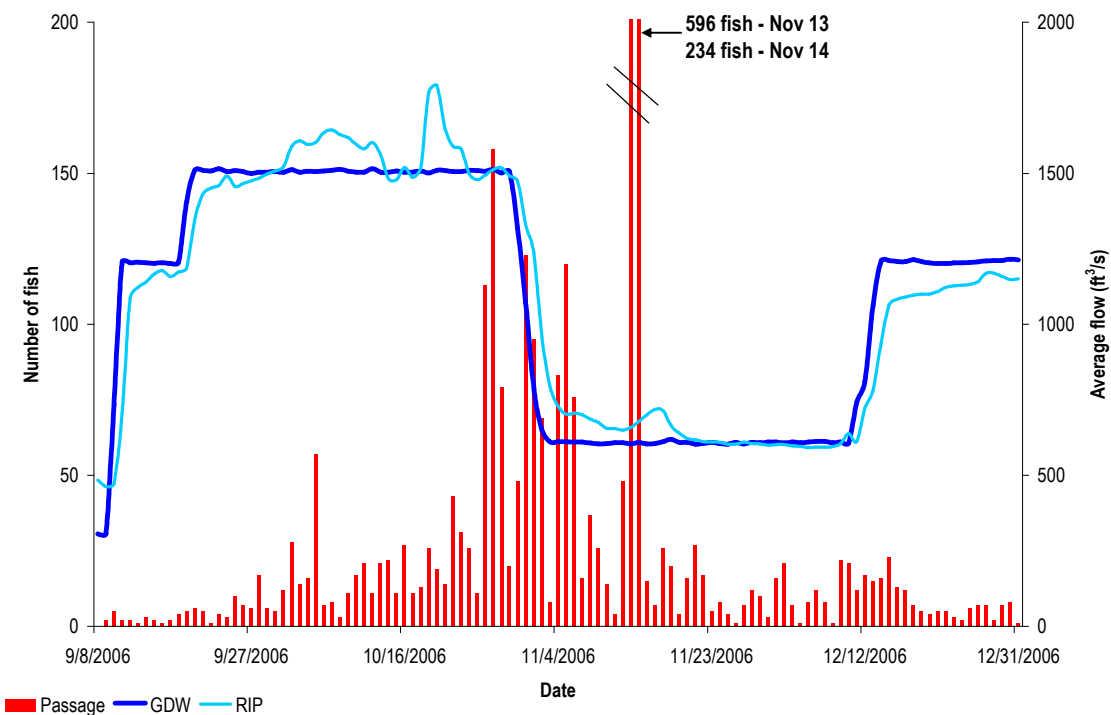
Figure 18. Daily passage of Chinook salmon at the Stanislaus River weir and average daily flow at Goodwin dam (GDW) and Ripon (RIP) (Data source: CDEC – http://cdec.water.ca.gov) from September 8 − December 31, 2006. This time period generally corresponds with annual CDFG escapement surveys.
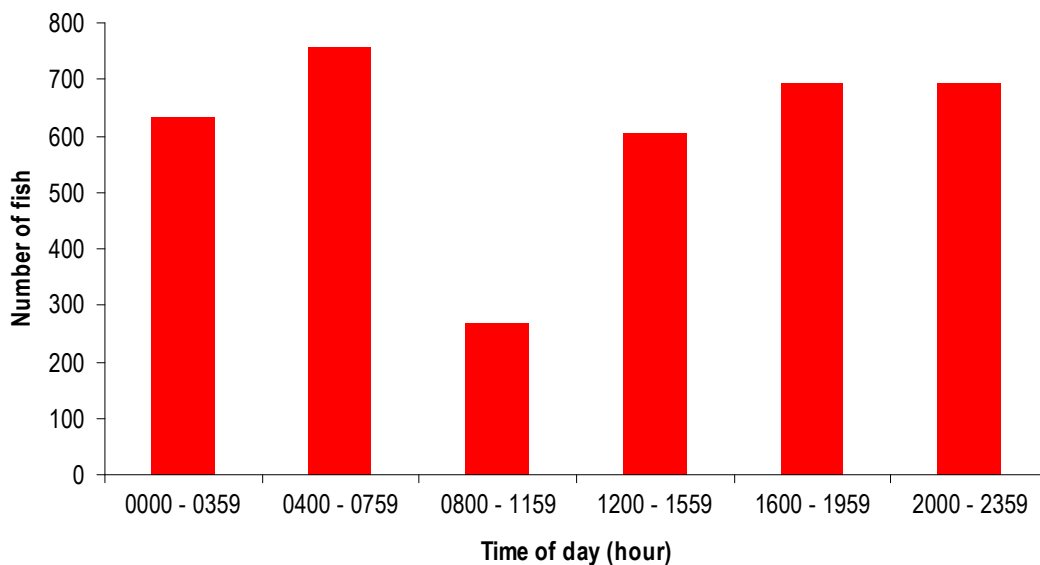
Figure 19. Daily passage counts of Chinook salmon throughout the sampling season in 4-hour time blocks. Differences in diel Chinook salmon passage was not significant among the different time periods (ANOVA: F = 0.66, P = 0.66).

Sex ratios for the entire Chinook salmon escapement were 52% female (n = 1,608), 36% male (n = 1,111), and 12% unknown (n = 356); while nine (82%) of the 11 spring-run Chinook salmon counted in May and June 2007 were female (Figure 20). Male and female size class distributions were significantly different (ANOVA: $F = 275.4$, $P < 0.0001$) (Figure 21). Mean total length for non-adipose fin clip Chinook salmon were: male 821 mm (n = 1,098), female 745 mm (n = 1,545), and unknown 693 mm (n = 451); while all Chinook salmon combined had a mean total length of 759 mm (Table 3). In all, 2% of the Chinook salmon run had adipose fin clips. Interestingly, the eleven spring-run fish had a much higher percentage (36%) of adipose fin clips.
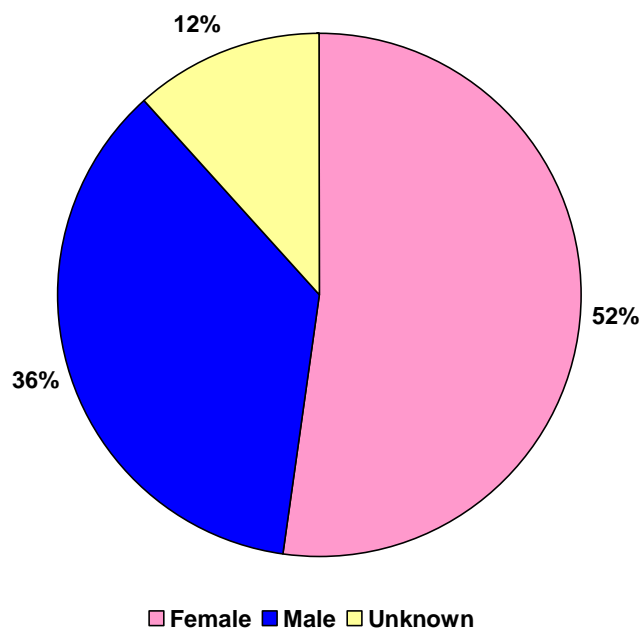
Figure 20. Sex ratios of Chinook salmon observed at the Stanislaus River weir.
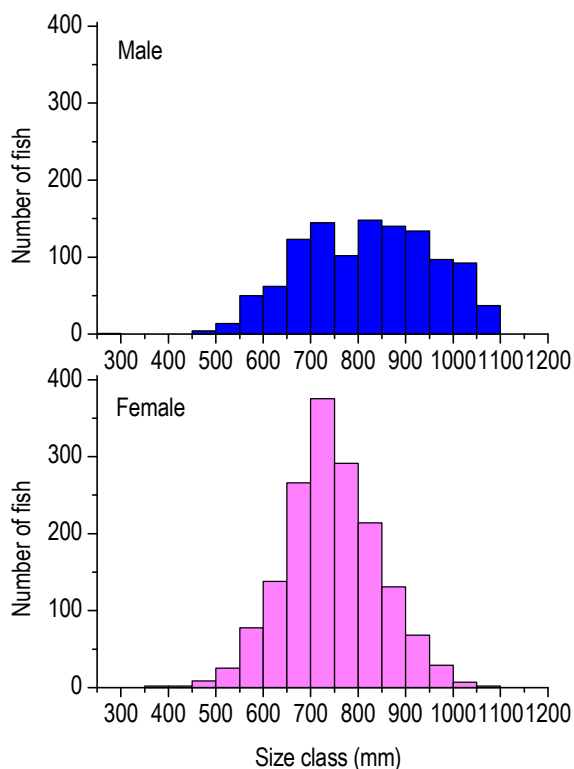
Figure 21. Length frequency of males and females determined from RiverWatcher 'Up' passage data collected from September 8, 2006 – June 25, 2007 (total numbers reflect only fish moving upstream and is not directly comparable to net passage). Male and female size class distributions were significantly different (ANOVA: F = 275.4, P < 0.0001).

Table 3. RiverWatcher 'Up' passage data for Chinook salmon from September 8, 2006 – February 27, 2007 (total numbers reflect only fish moving upstream and is not directly comparable to net passage).

Sex – Adipose Fin Clip	Range Total Length (mm)	Mean Total Length (mm)	95% CI (mm)	n
Male – No	273 - 1071	821	821 ± 8	1098
Male – Yes	542 - 1025	808	808 ± 56	27
Male – Unknown	504 - 1021	732	732 ± 58	22
Female – No	365 - 1054	745	745 ± 5	1545
Female – Yes	567 - 958	764	764 ± 39	31
Female – Unknown	470 - 865	695	695 ± 24	51
Unknown – No	349 - 1063	693	693 ± 12	451
Unknown – Yes	609 - 743	657	657 ± 86	3
Unknown – Unknown	395 - 1071	718	718 ± 15	335
Combined	273 - 1071	759	759 ± 4	3563

In all, 12 *O. mykiss* were counted with the first fish recorded on September 24, 2006 and the last fish recorded on June 15, 2007 (Table 4). Females comprised 42% (n = 5) of the passage while the remaining 58% were of undetermined sex. One female *O. mykiss* with an adipose fin clip passed the weir on October 11, 2006 (TL: 378 mm).

Table 4. RiverWatcher data for O. mykiss collected from September 8, 2006 – June 25, 2007.

Sex – Adipose Fin Clip	Range Total Length (mm)	Mean Total Length (mm)	95% CI (mm)	n
Female – No	483 - 554	522	522 ± 30	4
Female – Yes	378	—	—	1
Unknown – No	315 – 533	401	401 ± 78	5
Unknown – Unk	483 and 504	—	—	2
Combined	315 - 554	455	455 ± 47	12

Incidental fish species counted at the weir included Sacramento sucker (*Catostomus occidentalis*), Sacramento pikeminnow (*Ptychocheilus grandis*), hardhead (*Mylopharodon conocephalus*), striped bass (*Morone saxatilis*), common carp (*Cyprinus carpio*), unknown *Ictalurus* spp. and *Ameiurus* spp., Sacramento blackfish (*Orthodon microlepidotus*), American shad (*Alosa sapidissima*), black bass (*Micropterus* spp.), goldfish (*Carassius auratus*), and chum salmon (*Oncorhynchus keta*) (Table 5). The two chum salmon were both male and passed on October 30 and November 1, 2006, respectively.

Table 5. RiverWatcher data of native and non-native fish species counted at the Stanislaus River weir from September 8, 2006 – June 25, 2007.

Native Species	Range TL (mm)	Mean TL (mm)	Date Range	n
Sacramento sucker	240–1,122	443	9/11/06–6/25/07	3,388
Sacramento pikeminnow	240–840	426	9/11/06–3/31/07	451
Hardhead	240–852	434	4/26/07–6/23/07	390
Sacramento blackfish	252–792	415	9/12/06–4/28/07	73
Non-native Species	**Range TL (mm)**	**Mean TL (mm)**	**Date Range**	**n**
Striped bass	176–784	417	9/12/07–6/18/07	240
Common carp	360–1,062	747	9/11/06–6/21/07	171
Ictalurus spp. and *Ameiurus* spp.	240–690	366	9/14/06–6/25/07	81
American shad	240–750	538	4/25/07–6/24/07	53
Black bass	180–570	339	9/11/06–6/22/07	36
Goldfish	360–582	449	9/12/06–4/25/07	5
Chum salmon	777–785	781	10/30/06–11/1/06	2

We spent a total of 416.9 hours trapping this season (Table 6). Trapping and biological sampling occurred between November 2 and December 9, 2006. In all, 67 Chinook salmon were trapped and sampled, and scale samples were collected from 64 fish (Table 7). One Chinook salmon jumped out of the top of the live trap and subsequently fell back downstream; while two other Chinook salmon were released prior to

scale sample removal due processing difficulties. One trapped female Chinook salmon had an adipose fin clip (TL: 950 mm). No other fish species were captured in the live trap.

Table 6. Trapping events and trap effort (hours) between September 8, 2006 – June 25, 2007.

Event	Date (Closed)	Time (Closed)	Date (Open)	Time (Open)	Duration (Hours)
1	11/2/06	11:55	11/4/06	09:57	46.0
2	11/6/06	09:16	11/6/06	20:30	11.2
3	11/7/06	15:53	11/8/06	11:31	20.4
4	11/10/06	09:21	11/12/06	08:50	47.5
5	11/15/06	09:46	11/16/06	08:52	23.1
6	11/18/06	09:46	11/20/06	09:54	48.0
7	11/22/06	09:28	11/23/06	09:33	24.0
8	11/25/06	08:59	11/27/06	09:35	48.5
9	11/29/06	09:49	12/1/06	09:50	48.0
10	12/3/06	08:27	12/5/06	09:17	48.7
11	12/7/06	09:11	12/9/06	12:45	51.5
Total					**416.9**

Table 7. Chinook salmon trapping data collected at the Stanislaus River weir from November 2 – December 9, 2006 (Note: The combined total includes female with an adipose fin clip).

Sex	Mean TL/Depth Ratio	Range TL (mm)	Mean TL (mm)	95% CI	n
Male	4.02	600 – 1,100	861	861 ± 42	34
Female	4.24	630 – 1,000	797	797 ± 32	32
Combined	4.13	600 – 1,100	828	828 ± 27	67

Post-spawn Chinook salmon and *O. mykiss* carcasses washed onto the weir at certain times of the year (Table 8 and Table 9). In all, 24 Chinook salmon carcasses, and 4 Chinook salmon (barely alive) were washed onto the top of the weir during the sampling season. In all, 7 *O. mykiss* carcasses, and one *O. mykiss* (barely alive), were found at the weir site.

Table 8. Carcass and live Chinook salmon data collected at the Stanislaus River weir from September 8, 2006 –
June 25, 2007 (Note: All live fish were close to death, post spawn).

Species	Date	Dead	TL (mm)	Adipose Fin Clip	Sex
Chinook salmon	9/20/06	No	—	No	Male
Chinook salmon	11/22/06	No	830	No	Female
Chinook salmon	11/27/06	No	890	No	Male
Chinook salmon	12/7/06	No	735	No	Male
Chinook salmon	9/12/06	Yes	710	No	Female
Chinook salmon	11/9/06	Yes	780	No	Male
Chinook salmon	11/12/06	Yes	810	No	Male
Chinook salmon	11/16/06	Yes	660	No	Male
Chinook salmon	11/21/06	Yes	760	No	Male
Chinook salmon	11/28/06	Yes	950	No	Male
Chinook salmon	12/1/06	Yes	700	No	Male
Chinook salmon	12/2/06	Yes	790	No	Male
Chinook salmon	12/3/06	Yes	840	No	Male
Chinook salmon	12/3/06	Yes	665	No	Male
Chinook salmon	12/3/06	Yes	890	No	Male
Chinook salmon	12/5/06	Yes	720	No	Male
Chinook salmon	12/19/06	Yes	820	No	Female
Chinook salmon	12/26/06	Yes	940	No	Male
Chinook salmon	12/26/06	Yes	740	No	Male
Chinook salmon	12/27/06	Yes	915	No	Male
Chinook salmon	12/30/06	Yes	1095	No	Male
Chinook salmon	1/1/07	Yes	860	No	Male
Chinook salmon	1/2/07	Yes	—	No	Male
Chinook salmon	1/5/07	Yes	785	No	Male
Chinook salmon	1/19/07	Yes	750	No	Male
Chinook salmon	2/16/07	Yes	800	No	Male
Chinook salmon	2/19/07	Yes	1080	No	Male
Chinook salmon	2/21/07	Yes	690	No	Male

Table 9. Carcass and live O. mykiss data collected at the Stanislaus River weir from September 8, 2006 – June 25, 2007 (Note: We observed one live fish in poor health, which was quickly processed, and passed downstream of the weir).

Species	Date	Dead	TL (mm)	Adipose Fin Clip	Sex
O. mykiss	11/20/06	No	435	No	Unk
O. mykiss	12/3/06	Yes	478	No	Unk
O. mykiss	12/24/06	Yes	440	No	Unk
O. mykiss	1/18/07	Yes	390	No	Female
O. mykiss	1/22/07	Yes	625	No	Female
O. mykiss	2/3/07	Yes	445	No	Female
O. mykiss	2/21/07	Yes	490	No	Female
O. mykiss	2/23/07	Yes	445	No	Male

Stacking ratios ranged between 0% – 8.4% with a season average of 5.7%; well below the 15% stacking ratio limit guideline provided by CDFG.

Daily average flow at Ripon ranged from 462 – 1,790 ft^3/s with a season average of 1,045 ft^3/s. Daily average water temperature recorded at Ripon ranged from 7.8°C – 23.4°C with a season average of 13.5°C (Figure 22). Instantaneous water turbidity taken at the weir site ranged from 0.2 – 7.1 NTU with a season average of 1.1 NTU (Figure 23). Daily average dissolved oxygen at Ripon ranged from 7.6 – 11.7 mg/L with a season average of 9.5 mg/L (Figure 24).
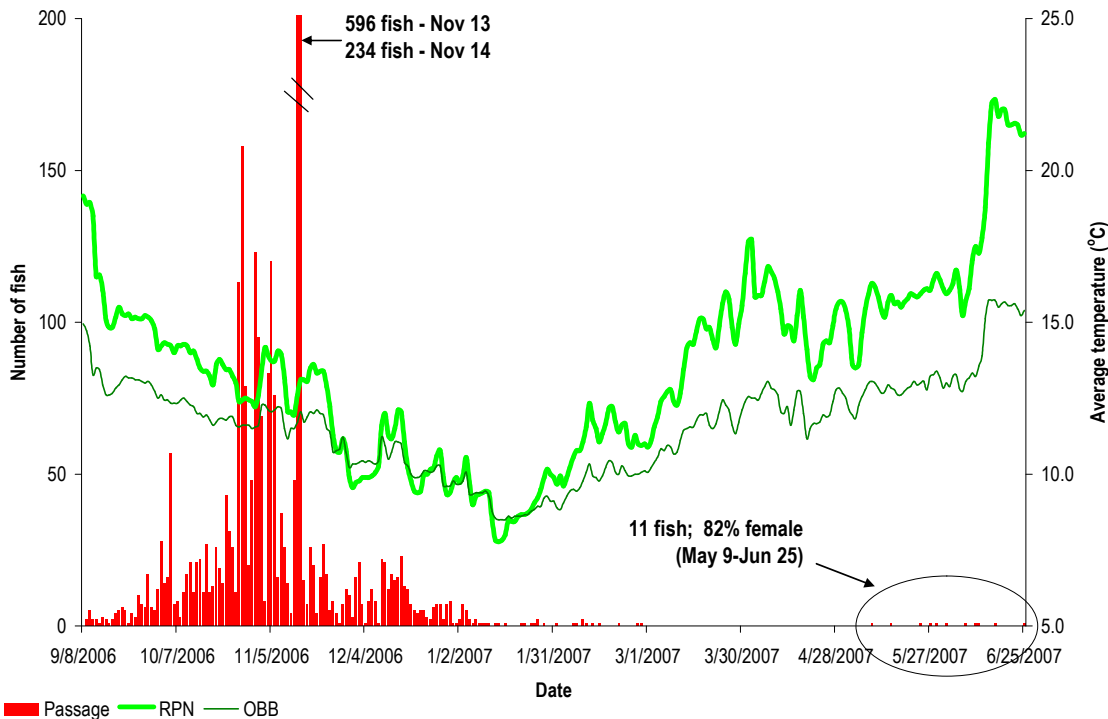
Figure 22. Chinook salmon daily passage at the Stanislaus River weir and average daily temperature at Ripon (RPN) and Orange Blossom bridge (OBB) from September 8, 2006 – June 25, 2007 [Data source: CDEC – http://cdec.water.ca.gov].

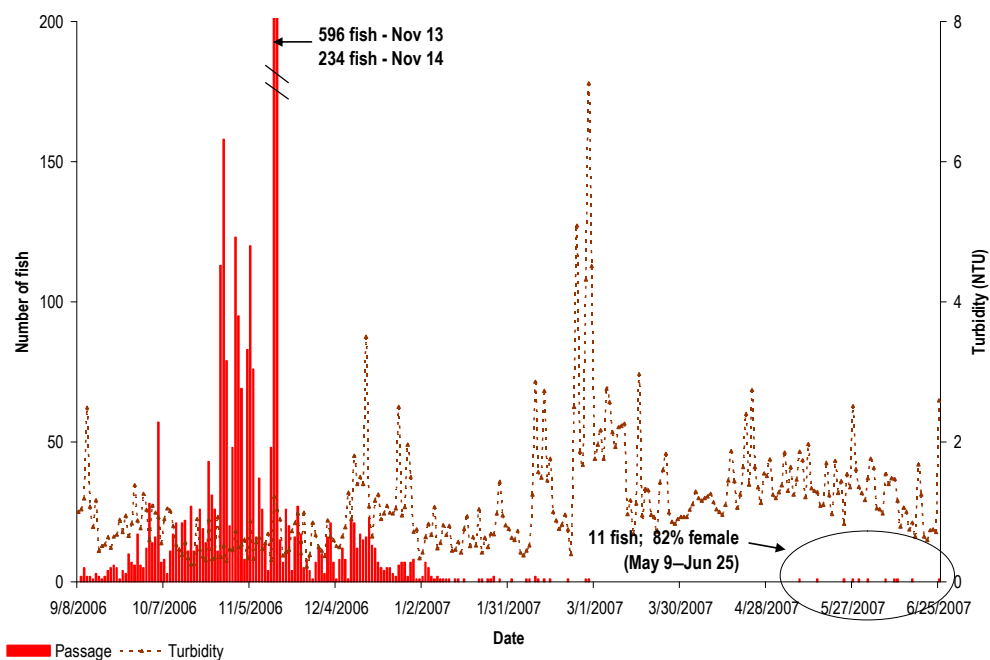*Figure 23. Chinook salmon daily passage at the Stanislaus River weir and daily instantaneous turbidity at the weir from September 8, 2006 – June 25, 2007.*
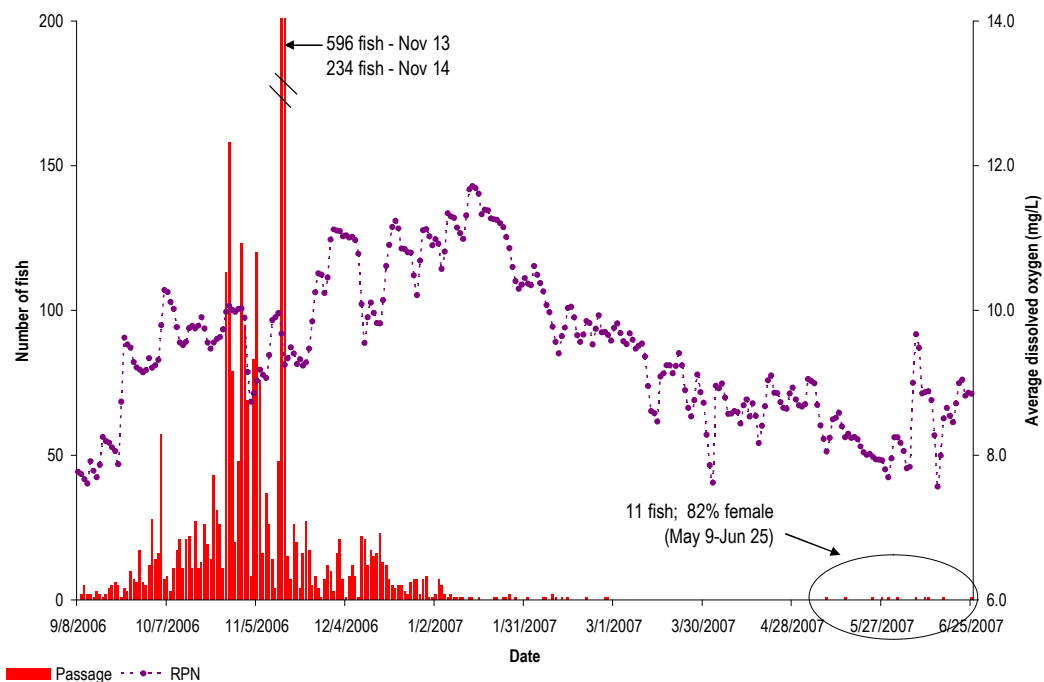

Figure 24. Chinook salmon daily passage at the Stanislaus River weir and average daily dissolved oxygen at Ripon (RPN) from September 8, 2006 – June 25, 2007 [Data source: CDEC – http://cdec.water.ca.gov].

Discussion

We completed the Stanislaus River weir installation on September 8, 2006 and operated continuously, with no technical problems, through June 25, 2007 (291 consecutive days). Operation and removal was consistent with previous years. Weir components (minus the substrate rail, winch stanchion, and solar pole) were removed from the river and stored either on-site or in a storage unit.

We counted 3,078 Chinook salmon and 12 *O. mykiss* at the weir during this sampling period. Shardlow and Hyatt (2004) determined RiverWatcher accuracy to be > 95% when adult Pacific salmon migration rates are less than 500 fish/h. Stanislaus River weir migration rates never approached this level (at peak, 596 fish/d), so we expect our data reflect highly accurate counts. Fewings (1994) tested the RiverWatcher in Iceland and found it to be 98.9% accurate, and Eatherley (2005) found the RiverWatcher to be 100% accurate when counting Atlantic salmon returns in a Scottish river. The majority (99.6%) of Chinook salmon passed the weir by February 27, 2007; however, an additional 11 Chinook salmon were counted between May 9 and June 25, 2007 demonstrating a life history pattern consistent with spring-run Chinook salmon based on migration timing (Yoshiyama et al. 1998; Moyle 2002). Historically, spring-run fish were prevalent in the San Joaquin River and its tributaries (Reynolds et al. 1993). Due to diversion dams, such as Goodwin Dam, spring-run stocks were considered all but extinct by the 1940s (Fry 1961). No counts or estimates for spring-run Chinook salmon populations have ever been made during the late spring on the Stanislaus River. Although the origins of these fish are unknown, these unique observations suggest additional monitoring may be warranted.

The one day peak passage of Chinook salmon (n = 596) on November 13 did not appear related to environmental conditions. However, escapement data from other studies indicate that peak, condensed passage events are a common pattern for Chinook salmon (Wiswar 1997; Harper 1998; Harper and Watry 2001; Anderson 2005). The majority of the total Chinook salmon passage (64%) occurred in a 22-day period from October 25 – November 15, 2006, coinciding with a drop and subsequent stabilization of flow from Goodwin Dam (see Figure 19). *O. mykiss* passage timing ranged from September 24, 2006 through June 15, 2007. Clear migration patterns in *O. mykiss* were difficult to detect due to the small sample size (n = 12).

We compared Chinook salmon passage and migration timing to various environmental factors and the only noticeable pattern observed was between flow and passage. The influence of flow on Chinook salmon return abundance and timing is generally well known (Pyper et al. 2006). We observed an increase in passage corresponding with the descending limb of the hydrograph based on Ripon flow. Water temperature remained low (< 15°C) throughout the fall period. Due to limited amounts of precipitation during the fall months, turbidity was very stable. Daily average dissolved oxygen at Ripon was well above the accepted 5 mg/L level for the entire sampling season. Daily average water temperature, turbidity, and dissolved oxygen did not appear to have any affect on Chinook salmon timing or migration.

Diel Chinook salmon passage was fairly consistent throughout the day with the exception of the time period from 0800 hours – 1159 hours. The perceived decreased passage during this time was likely a result of our weir cleanings and inspections; however, this reduced passage could naturally be a period of reduced migration. Cramer Fish Sciences staff observed fish preparing for passage and then falling back downstream when the team enters the river. Although we detected some disruption in migration due to weir operations, it was temporary and not statistically significant. Our stacking ratio ranged from 0% – 8.4% with a season average of 5.7%, well below the 15% stacking ratio limit guideline established by CDFG, indicating little interruption to migration resulting from weir operations.

According to Quinn (2005), males and females differ in size and age at maturity. Our analysis indicates that differences in length between sexes were significant. Age data from CDFG has not been completed, so we have not compared male versus female age at spawning. Quinn (2005) states that in most salmon

populations average male size is generally smaller than average female size due to a portion of 'jacks' in the run. Jacks, as defined by Quinn (2005), are sexually mature male salmon representing an age group younger than the youngest females in the population. A number of studies in Alaska have confirmed this trend over the years (Tobin and Harper 1998; Gates and Harper 2003; Gewin 2006). Our data show the opposite, with average total length for males to be 821 mm (n = 1,098) and females to be 745 mm (n = 1,545), possibly indicating that the number of jacks is limited on the Stanislaus River.

The female-to-male sex ratio observed at the weir was 1.5:1; however, we were unable to identify sex for 12% of Chinook salmon for various reasons, which may confound our ratio. When only the trapping data were considered, the female-to-male sex ratio was 1:1. However, a small sample size (n = 67) may skew the 1:1 ratio, we consider the 1.5:1 ratio to be more accurate as it is based on continuous video data (n = 3,078). O'Brien (2006) found Chinook salmon females comprised 33% and males comprised 67% of the population in the Gisasa River, Alaska. Gewin (2005) found almost the same sex ratio on the East Fork Andreafsky, Alaska in 2004. When evaluating sex ratio of the spring migrants, we found a female-to-male sex ratio of 8:1 which again may be a reflection of our small sample size. *O. mykiss* female-to-male sex ratio was also skewed at 9:1. Out of 20 fish (12 RiverWatcher, 8 other) one was male, nine were female, and ten were of an unknown sex. It is unknown whether this is an artifact of differences in male versus female spawning morphology, or if this is a true representation of the *O. mykiss* migrating in the Stanislaus River to spawn. Gates and Palmer (2006) found sex ratios in Alaska's Crooked and Nikolai creek's steelhead trout to be 1.5:1.

We counted 63 Chinook salmon with adipose fin clips (2%) passing the weir this season. Although origin of these fish is unknown, they are likely strays from one of several Central Valley hatcheries (i.e., Feather River, Nimbus, Mokelumne River, Merced River, Coleman, or Livingston Stone). Of the 11 Chinook salmon counted passing the weir in late spring, 4 had adipose fin clips (36%) reflecting a much higher adipose fin clip ratio, suggesting these migrants were of hatchery origin. Collection of biological data, which would aid in origin identification, is ineffective during periods of low passage density and was, therefore, not performed during this time period. We recorded one female *O. mykiss* with an adipose fin clip passing the weir on October 11, 2006 (TL: 378 mm). The closest known hatchery that releases steelhead trout is the Mokelumne River Fish Hatchery located on the Mokelumne River near the town of Clements, California. It is possible this fish strayed from the Mokelumne to the Stanislaus River, but Feather River, Nimbus and Coleman hatcheries are other potential sources.

Scale samples from 64 of the 67 fish trapped at the weir this season were given to CDFG for an ongoing age determination study. Age data from scale samples collected this season are not yet available (J. Guignard, CDFG, personal communication). Age data for 2005, including weir data and carcass survey data, have been completed by CDFG and are available for review as an addendum to Guignard (2007a).

We counted thirteen different species of fish at the weir this season. Interestingly, a pair of male chum salmon passed the weir in the fall, in addition to a variety of native and non-native species. To our knowledge, these two chum salmon are the only chum recorded on the Stanislaus River. Historically, chum salmon ranged into the Sacramento River drainage, but today are only known to exist in three California rivers: Smith, Klamath, and Trinity (Moyle 2002). We observed hardhead, a native cyprinid, passing the weir (n = 390) from April 26 – June 23, 2007, indicating a possible spawning migration up the Stanislaus River. American shad (n= 53) migration had similar timing to the hardhead, from April 25 – June 24, 2007. Sacramento suckers (n = 3,388) counted at the weir greatly outnumbered all other species combined. Sacramento suckers are prolific in the lower Stanislaus River and are widely distributed in central and northern California. Sacramento sucker spawning generally takes place between late February and early June (Moyle 2002); however, Sacramento suckers were present throughout the sampling period at the weir site.

Annual escapement surveys are conducted on the Stanislaus River by CDFG. Spawning escapement estimates have been conducted on the Stanislaus River since 1940 (Fry 1961). In more recent years, CDFG has

conducted carcass surveys along with live salmon and redd counts, estimates of pre-spawn mortality, and coded wire tagging (CWT) sampling. California Department of Fish Game sampling extends from Goodwin Dam (rkm 93.5) downstream to Jacob Myers Park in Riverbank (rkm 52.8).

Three models have been used by CDFG to estimate escapement using carcass tag-and-recovery data over the years (Snider et al. 1999). They are the Petersen (Ricker 1975), Schaefer (Schaefer 1951), and Jolly-Seber (Seber 1982) methods. Law (1994) conducted tests on all three models and found the Petersen to be the simplest and least accurate of the three. Based on Laws' analysis of the other two methods, the Schaefer model will overestimate escapement, and the Jolly-Seber model will underestimate the spawner escapement (Boydstun 1994). Both the Schaefer and Jolly-Seber models were used by CDFG to calculate escapement in 2006 on the Stanislaus River in 2006.

This season, carcass surveys on the Stanislaus River began October 2, 2006 and ended on December 29, 2006. Precise methods and estimate calculations are detailed in Guignard (2007b). Based on the Schaefer model, 1,923 Chinook salmon were estimated to have returned to the Stanislaus, whereby the Jolly-Seber model estimated 1,276 Chinook salmon. Weir counts for September 8, 2006 through December 29, 2006 were 3,012 Chinook salmon; 36% greater than the Schaefer estimate and 58% greater than the Jolly-Seber model estimates. Weir estimates, as direct counts of live fish, provide valuable data to assess reliability and potential for bias in current mark-recapture escapement estimates. Comparisons for 2006 estimates indicate that carcass mark-recapture escapement estimates are negatively biased, regardless of the statistical model applied to the data. Peak timing at the weir occurred during the second week in November, two weeks earlier than that observed by carcass surveys conducted by CDFG.

Carcass surveys have been used in the Pacific Northwest for many years and include several assumptions necessary to develop accurate estimates. One of the key assumptions for a mark-recapture experiment is 'equal catchability' which is difficult to achieve (Cavallo 2000). All carcasses must have the same probability of being recovered by survey crews. Heindl (1989) states the accuracy of mark-recapture experiments depends on the extent marked and unmarked individuals are evenly mixed within the population. Randomized sampling may help meet this assumption, but is difficult to execute and rare among carcass surveys. In addition, level of effort is difficult to standardize in carcass surveys and can influence final escapement estimates. Consistent with our findings, Cavallo (2000) conducted simulations indicating that carcass mark-recapture escapement estimates tend to underestimate actual population size.

Although carcass surveys have limitations, they do provide important information to scientists and managers not necessarily available from weir operations. This information includes biological data including otoliths and CWT return data (Johnson et al. 2007). Carcass surveys can also provide spatially-explicit redd and live fish count information, which may inform and direct future habitat restoration work. Although the weir can provide accurate passage numbers and high-quality scale samples, otoliths and CWTs cannot be recovered from live fish. Studies which combine both methodologies, using weir counts to determine spawning population size and carcass surveys to determine spawning distribution and to collect otoliths and CWTs, will provide the best overall data.

In addition to the information presented in this annual report, the Stanislaus River weir has provided five years of highly accurate escapement data to compare against mark-recapture survey data, and to aid managers in evaluating fisheries technology and efficiency, and will be detailed in an upcoming comprehensive report. This project on the Stanislaus River has demonstrated the efficacy of determining escapement in Central Valley rivers with weir technology, and highlights the accuracy and reliability of this monitoring tool. Year-round operation of the weir could provide additional, valuable insight into Chinook salmon population dynamics on the Stanislaus River, in addition to other migratory fishes (e.g., hardhead).

Recommendations

Over the past five years of weir operations on the Stanislaus River, we have made many changes, modifications, and upgrades to refine a reliable and efficient monitoring tool. Based on our experience, we would like to provide the following recommendations for future studies:

Short-term recommendations include:

- Conduct weir installation, monitoring, and removal in the same manner as it was done this season
- Inspection of the RiverWatcher camera by a Vaki engineer before installation next season
- Replace viewing lane acrylic
- Make minor repairs to the resistance board panels prior to use next season

Long-term recommendations include:

- Research motion detector technology to integrate with the RiverWatcher light/scanner to conserve battery power during night time hours
- Redesign downstream live trap and design a corresponding weir panel to accommodate new downstream live trap design
- Upgrade to a faster, more powerful RiverWatcher computer system
- Upgrade to the new, higher quality, RiverWatcher camera to gain higher resolution photograph data
- Redesign live trap lids to allow for safe, easy access into the live trap
- Research live video feed cameras that could be mounted on-site with views of the weir along with connection to the internet to be able and view the weir site real time from an office PC
- Modify trapping protocol to increase overall capture numbers for the season
- Replace resistance board panel PVC after one more monitoring season
- Extend monitoring to year round operation

Acknowledgements

References

Anderson, J. L. 2005. Abundance and run timing of adult pacific salmon in Big Creek, Becharof National Wildlife Refuge, 2004. U.S. Fish and Wildlife Service, King Salmon Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2005-12, King Salmon, Alaska.

Boydstun, L. B. 1994. Evaluation of the Schaefer and Jolly-Seber methods for the fall-run Chinook salmon, *Oncorhynchus tshawytscha*, spawning run into Bogus Creek, Upper Klamath River. California Fish and Game 80:1-13.

Cavallo, B. 2000. A critique of Central Valley salmon spawning surveys. California Department of Water Resources, Environmental Services Office, Sacramento.

Eatherley, D. M. R., J. L. Thorley, A. B. Stephen, I. Simpson, J. C. MacLean, and A. F. Youngson. 2005. Trends in Atlantic salmon: the role of automatic fish counter data in their recording. Scottish Natural Heritage Commissioned Report No. 100 (ROAME No. F01NB02).

Fewings, G. A. 1994. Automatic salmon counting technologies: a contemporary review. Bensinger Liddell Memorial Fellowship 1992/93. Atlantic Salmon Trust, Pitlochry, Perthshire.

Foss, S. 2005. Salvage of hatchery-released juvenile steelhead at the State Water Project and Central Valley Project fish facilities. Interagency Ecological Program for the San Francisco Estuary Newsletter 18:43-46.

Fry, D. H. 1961. King salmon spawning stocks of California's Central Valley, 1940-1959. California Fish and Game 47:55-71.

Gates, K. S. and D. E. Palmer. 2006. Abundance and run timing of adult steelhead trout in Crooked and Nikolai creeks, Kenai Peninsula, Alaska, 2006. U.S. Fish and Wildlife Service, Kenai Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2006-13, Kenai, Alaska.

Gates, K. S. and K. C. Harper. 2003. Run timing and abundance of adult Salmon in the Tuluksak River, Yukon Delta National Wildlife Refuge, Alaska, 2002. U.S. Fish and Wildlife Service, Kenai Fish and Wildlife Field Office. Alaska Fisheries Data Series Number 2003-1, Kenai, Alaska.

Gewin, C. S. 2005. Abundance and run timing of adult Pacific salmon in the East Fork Andreafsky River, Yukon Delta National Wildlife Refuge, Alaska, 2004. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Number 2005-13 Fairbanks, Alaska.

Gewin, C. S. 2006. Abundance and run timing of adult Pacific salmon in the East Fork Andreafsky River, Yukon Delta National Wildlife Refuge, Alaska, 2005. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Number 2006-7 Fairbanks, Alaska.

Guignard, J. 2007a. Addendum to the Stanislaus River fall Chinook salmon escapement survey, 2005. California Department of Fish and Game. U.S. Bureau of Reclamation, contract #R054004.

Guignard, J. 2007b. Stanislaus River fall Chinook salmon escapement survey, 2006. California Department of Fish and Game. U.S. Bureau of Reclamation, contract #R0640001.

Harper, K. C. 1998. Run timing and abundance of adult salmon in the Kwethluk River, Yukon Delta National Wildlife Refuge, Alaska, 1992. U.S. Fish and Wildlife Service, Kenai Fishery Resource Office, Alaska Fisheries Technical Report Number 44, Kenai, Alaska.

Harper, K. C. and C. B. Watry. 2001. Abundance and run timing of adult salmon in the Kwethluk River, Yukon Delta National Wildlife Refuge, Alaska, 2000. U.S. Fish and Wildlife Service, Kenai Fishery Resource Office, Alaska Fisheries Data Series Number 2001-4, Kenai, Alaska.

Heindl, A. L. 1989. Columbia River Chinook salmon stock monitoring project for stocks originating above Bonneville Dam, field operations guide. Columbia Inter-Tribal Commission, Technical Report 87-2 (revised), Portland, Oregon.

Johnson, D. H., B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O'Neil, and T. N. Pearsons. 2007. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Kondolf, G. M., A. Falzone, and K. S. Schneider. 2001. Reconnaissance-level assessment of channel change and spawning habitat on the Stanislaus River below Goodwin Dam. Report of G. Mathias Kondolf to U.S. Fish and Wildlife Service, Sacramento, California.

Law, P. M. W. 1994. Simulation study of salmon carcass survey capture-recapture methods. California Fish and Game 80:14-28.

Moyle, P. B. 2002. Inland fishes of California, revised and expanded. University of California Press, California. 502 pp.

National Ocean and Atmosphere Administration (NOAA). 2005. Federal Register. Endangered and threatened species; designation of critical habitat for seven evolutionary significant units of Pacific salmon and steelhead in California; final rule. Vol. 70, No. 170, pp. 52488-52627.

O'Brien, J. P. 2006. Abundance and Run Timing of Adult Salmon in the Gisasa River, Koyukuk National Wildlife Refuge, Alaska, 2005. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Number 2006-3 Fairbanks, Alaska.

Pacific States Marine Fisheries Commission (PSMFC). 2005. *Central Valley Chinook salmon scale collection protocol,* Central Valley Cohort Reconstruction Project.

Pyper, B., J. B. Lando, and C. Justice. 2006. Analyses of weir counts and spawning surveys of adult Chinook salmon in the Stanislaus River. Cramer Fish Sciences, Gresham. 65 pp.

Quinn, T. P. 2005. The behavior and ecology of Pacific salmon & trout. American Fisheries Society, Bethesda, Maryland. 378 pp.

Reynolds, F. L., T. J. Mills, R. Benthin, and A. Low. 1993. Restoring Central Valley streams: a plan for action. California Department of Fish and Game.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Canada Department of Environment, Fisheries and Maine Service Bulletin 191.

Sacramento River Partners. 2001. Riparian restoration plan for the Mohler Tract on the Stanislaus River (River Mile 12.3), Ripon, California. Final Report. June 20, 2001. Dan Efseaff, editor. Chico, California.

Schaefer, M. B. 1951. Estimation of the size of animal populations by marking experiments. U.S. Fish and Wildlife Service Bulletin 52:189-203.

Seber, G. A. F. 1973. Estimation of animal abundance and related parameters. Griffin, London. 506 pp.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, 2nd edition, MacMillan, New York. 654 pp.

Shardlow, T. F. and K. D. Hyatt. 2004. Assessment of the counting accuracy of the Vaki infrared counter on chum salmon. North American Journal of Fisheries Management 24:249-252.

Snider, B., B. Reavis, and S. Hill. 1999. Upper Sacramento River fall-run Chinook salmon escapement survey; September – December 1998. Stream Evaluation Program Technical Report No. 99-2. California Department of Fish and Game, Sacramento.

Stewart, R. 2002. Resistance board weir panel construction manual. Alaska Department of Fish and Game, Division of Commercial Fisheries, Arctic-Yukon-Kuskokwim Region, Regional Information Report No. 3A02-21, Fairbanks, Alaska.

Stewart, R. 2003. Techniques for installing a resistance board fish weir. Alaska Department of Fish and Game, Division of Commercial Fisheries, Arctic-Yukon-Kuskokwim Region, Regional Information Report No. 3A03-26, Fairbanks, Alaska.

Tobin, J. H. 1994. Construction and performance of a portable resistance board weir for counting migrating adult salmon in rivers. U.S. Fish and Wildlife Service, Kenai Fishery Resource Office, Alaska Fisheries Technical Report Number 22, Kenai, Alaska.

Tobin, J. H. and K. C. Harper. 1998. Abundance and run timing of adult salmon in the East Fork Andreafsky River, Yukon Delta National Wildlife Refuge, Alaska, 1997. U.S. Fish and Wildlife Service, Kenai Fishery Resource Office, Alaska Fisheries Progress Report Number 98-2, Kenai, Alaska.

U.S. Department of the Interior (USDOI). 2005. Central Valley Project Improvement Act – 10 Years of Progress. Sacramento, California. www.usbr.gov/mp/cvpia

U.S. Fish and Wildlife Service (USFWS). 2001. Final Restoration Plan for the Anadromous Fish Restoration Program. http://www.delta.dfg.ca.gov/afrp/documents/finalrestplan.pdf

Wiswar, D. W. 1997. Abundance and run timing of adult salmon in the South Fork Koyukuk River, Kanuti National Wildlife Refuge, 1996. Alaska Fisheries Data Series Number 1997-5, Fairbanks, Alaska.

Yoshiyama, R. M., F. W. Fisher, and P. B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.

Appendix 1: Stanislaus River Points of Interest

Point	Purpose/Significance	Operator	rkm (RM)
New Melones Dam	Constructed in 1978; Flood control, water supply, power generation, recreation	BOR	(60)
Tulloch Dam	Constructed in 1957; Flood control, water supply, recreation	TriDam	(55)
Goodwin Dam	Constructed in 1913; Irrigation water diversion canals	BOR	93.9 (58.4)
Knights Ferry covered bridge	Historic feature	ACOE	87.4 (54.3)
Knights Ferry gravel augmentation	Habitat improvement	CDFG	87.4 -86.6 (54.3 – 53.8)
Orange Blossom Bridge	Temperature gauging station	DWR	75.5 (46.9)
Oakdale rotary screw traps	Juvenile salmonid abundance and out-migration timing	Oakdale Irrigation District (OID)	64.5 (40.1)
Stanislaus River weir	Adult passage and timing	AFRP/TriDam	49.9 (31)
Hwy 99 bridge (Ripon)	Temperature, discharge and DO	USGS	25.4 (15.8)
Caswell Memorial State Park	Juvenile salmonid abundance and out-migration timing	AFRP	13.8 (8.6)
Two Rivers Trailer Park	San Joaquin-Stanislaus confluence	—	0 (0)

Appendix 2: Stanislaus River Species List

Common name	Species name	Native (Yes or No)
American Shad	*Alosa sapidissima*	No
Bigscale Logperch	*Percina macrolepida*	No
Black Crappie	*Pomoxis nigromaculatus*	No
Bluegill Sunfish	*Lepomis macrochirus*	No
Brown Bullhead	*Ictalurus nebulosus*	No
Channel Catfish	*Ictalurus punctatus*	No
Chinook Salmon	*Oncorhynchus tshawytscha*	Yes
Chum Salmon	*Oncorhynchus keta*	No
Common carp	*Cyprinus carpio*	No
Golden Shiner	*Notemigonus crysoleucas*	No
Goldfish	*Carassius auratus*	No
Green Sunfish	*Lepomis cyanellus*	No
Hardhead	*Mylopharodon conocephalus*	Yes
Hitch	*Lavinia exilicauda*	Yes
Inland Silverside	*Menidia beryllina*	No
Largemouth Bass	*Micropterus salmoides*	No
Pacific Lamprey	*Lampetra tridentata*	Yes
Prickly Sculpin	*Cottus asper*	Yes
Rainbow Trout/Steelhead	*Oncorhynchus mykiss*	Yes
Redeye Bass	*Micropterus coosae*	No
Red Shiner	*Cyprinella lutrensis*	No
Riffle Sculpin	*Cottus gulosus*	Yes
Sacramento Blackfish	*Orthodon microlepidotus*	Yes
Sacramento Pikeminnow	*Ptychocheilus grandis*	Yes
Sacramento Sucker	*Catostomus occidentalis*	Yes
Smallmouth Bass	*Micropterus dolomieu*	No
Spotted bass	*Micropterus punctulatus*	No
Striped Bass	*Morone saxatilis*	No
Threadfin Shad	*Dorosoma petenense*	No
Tuleperch	*Hysterocarpus traski*	No
Western Mosquitofish	*Gambusia affinis*	No
White Catfish	*Ictalurus catus*	No
White Crappie	*Pomoxis annularis*	No